UPFC FOR ANALYSIS OF RELAY PERFORMANCE DURING POWER SWING CONDITION

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF

Master of Technology

In

Electrical Engineering

By

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Rourkela-769008

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Gitesh Kumar

Under the guidance of

Prof. Sanjeeb Mohanty

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Dedicated

To

My beloved parents

Department of Electrical Engineering

National Institute of Technology , Rourkela

Certificate

This is to certify that the thesis entitled, "**UPFC for Analysis of Relay performance during Power swing condition**" submitted by Mr. Gitesh Kumar in partial fulfillment of the requirements for the award of Master of Technology Degree in electrical Engineering with specialization in "Power Electronics and Drives" during session 2013-15 at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance. This work has not been submitted at other University/ Institute for the award of any degree or diploma.

Date:

Place: Rourkela

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Last but not least I would like to thank my parents, who taught me to work hard by their own example. They provided me much support being apart during the whole tenure of my stay in NIT Rourkela.

GITESH KUMAR

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Abstract

Distance relay plays important role in the transmission line as far as protection of the system is concerned. Now a days facts devices has been widely used in transmission line because of their numerous advantages, but its present in transmission line leads to some obstacle in operation of distance protection. Present of FACTS controller causes change in the measured impedance of the distance relay which in turn can cause undesirable tripping or improper operation of relay. So it is a challenge to correct the operation of distance relay in the presence of FACTS devices so that FACTS device can be used properly without any interruption. For this purpose, it is necessary to analyze the impact of these devices on relay under different circumstances so that new reach setting of distance relay can be made accordingly. This study presents effect of series and shunt compensator as well as UPFC on performance of distance relay with both analytic and simulation methods .In this study, its effects have been seen on the relay by comparing R-X characteristic and apparent impedance for different fault condition and location of the fault.

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List of Abbreviations

C_S	Dc storage capacitor
V_{dc}	DC side voltage of voltage source converter
VSC_1	Voltage source converter 1
VSC_1	Voltage source converter 2
R_{ab}	Impedance seen by relay
E_{relay}	Voltage measured by potential transformer
I_{relay}	Current measured by current transformer
Z_f	Reach setting of relay
Z_{app}	Apparent impedance of relay
P_a	Accelerating power
P_m	Mechanical power input to generator
P_e	Electrical power output
R_f	Fault Resistance

Z	Total impedance seen by relay
Z_1	Positive sequence impedance of relay
Z	Corrected impedance of the relay
V_{1s}, V_{2s}, V_{0s}	Sequence phase voltages at the relay location;
$V_{1pq}, V_{2pq}, V_{0pq}$	Series sequence phase voltages injected by UPFC;
$I_{1s}, I_{2s,} I_{0s}$	Sequence phase currents at the relay location;
$I_{1line,} I_{2line}, I_{0line}$	Sequence phase currents in transmission line;
$I_{1f}, I_{2f,} I_{0f}$	Sequence phase currents in the fault;
$I_{1sh}, I_{2sh}, I_{0sh}$	Shunt sequence phase currents injected by UPFC
Z_1, Z_0	Sequence impedance of the transmission line;
n	Per-unit distance of a fault from the relay location
V_R, I_R	Phase voltage and current at relay point;
I_{R0}	Zero sequence phase current;
I_{relay}	Relaying current

CHAPTER 1

INTRODUCTION

1.1 Introduction

In the recent years various types of power electronics device based controllers have been introduced to the power system. Application of these devices in transmission line can have greater benefits in both technical and economical ways, such as better control over power flow, better voltage regulation, and better system stability. However, the application of these controllers in transmission lines leads to certain difficulties for the operation of distance relay as because of current injected by shunt controller to the transmission line and variable ac voltage added by series controller in the series with the transmission line. UPFC is a device having both series and shunt controller connected via dc link, and its presence affects the R-X characteristics of distance relay as it directly changes in the measured impedance seen by relay. As we know that operation of distance relay is basically based on measurement of the impedance from relay location to fault point, change in the impedance seen by relay can cause undesired and improper tripping of the relay .To avoid such an incident it is necessary to investigate the effect of these devices on performance of relay under different circumstances and make relay setting taking consideration of these impacts .In the proposed study effect of installation of Shunt and Series compensator as well as of UPFC on distance relay is investigated under different types of fault and its location.

1.2 Literature review

The demand of electric energy is increasing day by day, so it has become important to make better use of available resources. Some steps have already been taken. Introduction of FACTS devices into the power system is one of them .In recent years, various power electronic devices and control technologies have been introduced to make utilization of the power system [1].FACTS devices are the devices based on the power electronics devices. FACTS devices have mainly two categories one is Shunt compensators mainly used for improving voltage profile other is Series compensators which basically controls the flow of power along the line.. The UPFC introduced by Gyugyi, L is the combination of above two so it is most versatile FACTS device, and has benefit of both series and shunt controller. Various mathematical models of UPFC have been introduced depend upon various purpose of application [2-3]. UPFC has several advantages such as control over the reactive power and at same time it improves voltage profile of the line. As it has so many advantages there are some demerits also such as it introduces harmonics and non-linearity to system which create problem in the operation of Distance protection [4-5].Presence of UPFC causes measured impedance of distance relay to change, and changes that occurs depends upon the compensation technique used and location of fault .And important point to notice is both shunt and series controller has some contribution to the changes that takes place. Analysis shows that when shunt controller i.ee STATCOM when operated as inductance (absorb reactive MVAr) relay undergoes to over reach, and when it acts as capacitor relay goes to under reach condition [7-10]. In similar passion Series controller i.e. SSSC also changes the R-X plot of the distance relay which in turn result in maloperation of relay.

Now coming to distance relays operation, it basically measures the impedance between fault locations to the point of relaying, and if it becomes less than a pre calculated measurement (known as reach setting of relay) it will operate otherwise it won't. Now if due to certain reason that measured impedance increases or decreases then it directly affects the tripping of relay means relay may mal operate. Distance relay can be simulated in MATLAB/ Simulink with the different algorithm for various fault so that the characteristics can be observed [11].

Impact of UPFC on performance of distance relay for various fault condition like L-L fault, L-G fault etc. has been analyzed for different position of UPFC i.e. in midpoint of or at beginning [12-14]. The analysis involves calculation of measured impedance at relay point and analysis of R-X plot of relay for different fault and UPFC location. Like other disturbances it is necessary to analyze its effect during a power swing condition. Now second important point about distance relay is it also maloperates during power swing condition as parameter variation during power swing cause measured impedance to change such that it enter into operating characteristics of the relay[15]. But the thing is it must not operate for such a condition because system should be given some time to regain its synchronism, hence it should discriminate between such a disturbance and system fault condition .Power swing Block (PSB) is used for this purpose it basically block operation of distance relay at the power swing condition and also discriminate between system fault and such disturbances. Several studies have been done to analyze the effect of power swing on distance relay for the transmission line with UPFC compensation because like other disturbances and fault during power swing also shunt and series part of UPFC adversely affect performance of distance relay [16].

1.3 Research motivation

In order to improve control of flow of power and stability of power system FACTS devices are widely used in transmission as well as a distribution system. Among all of FACTS controllers, Unified Power Flow Controller (UPFC) is versatile facts device, as it has advantages of both series and shunt controller. But the presence of UPFC has some adverse effect on distance relay used in transmission line, it can cause changes in the measured impedance seen by distance relay which may result in mal operation of distance relay in the form of either under reach or over reach which depends upon the type of compensation technique. So there is a motivation to analyze the effect of UPFC on distance protection so that suitable relay setting can be done accordingly. In proposing study impact of UPFC on distance relay is considered during different fault condition. The proposed study measured impedance to the fault point for three phase fault is considered with variation in fault resistance and fault location.

1.4 Objectives

The proposed approach analyzes measured impedance of the relay to the fault point with variation in fault resistance, fault location and for different fault condition.

The objectives of the research are:

Calculation of apparent impedance of distance relays analytically for various system faults and location of faults in the presence of UPFC.

1. Design distance relay in MATLAB/ Simulink to get R-X characteristics of relay.
2. Analysis of impact of shunt and series controller individually and collectively on performance of distance relay using MATLAB/Simulink.

1.5 Thesis Organization

Chapter 1

Chapter 1 gives a brief review of the problem associated with the operation of distance relay for the transmission line with UPFC. The objectives of the research are also highlighted

Chapter 2

Chapter 2 gives information about the FACTS compensators used for analysis with their merits in the the transmission line .This chapter also includes calculation of apparent impedance of relay for the system with UPFC analytically for L-G fault and double line fault.

Chapter 3

Chapter 3 presents simulation of the distance relay and power system in MATLAB/Simulink. As well as the analysis of result obtained from it.

Chapter 4

Chapter 4 presents comprehensive summary and conclusions of proposed research work as well as the future scope of the work.

CHAPTER 2

IMPACT OF FACTS DEVICES ON DISTANCE RELAY

2.1 FACTS Devices

2.1.1 Static Shunt Compensator (STATCOM)

STATCOM means static synchronous compensator which is similar to a basic rotating synchronous motor (generally known as synchronous condenser) which provides reactive power to system when it is over excited and absorb it when it is made to run under excited, in similar passion voltage source converter based controller is made to exchange either absorb or deliver reactive power with the system by suitable controlling technique. It can also be made to exchange active power when a storage device is in use with the system. During operation if output voltage of controller is greater than the bus voltage then controller provides reactive power to the system and if output voltage is less than the bus voltage controller takes reactive power from system. Third case is also possible of bus voltage and controller output voltage are same then there is reactive power exchange with the system.

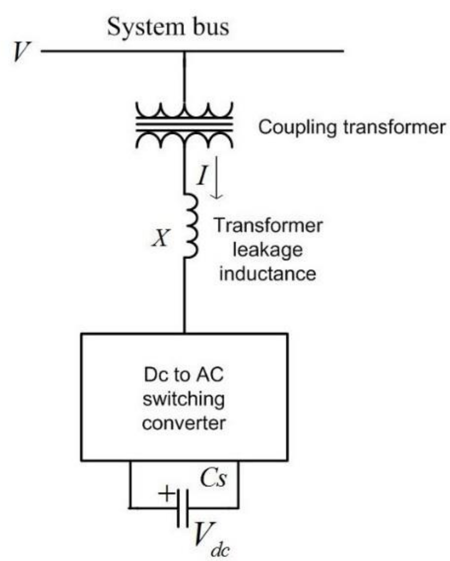

Figure 2.1 schematic diagram of STATCOM

2.1.2 Static Series Compensator (SSSC)

As we have seen that STATCOM has so many merits but it cannot be used to control the flow of power in the transmission line at a system voltage. The main factors affects flow of power in transmission line are Series impedance of line and load angle i.e. angle between voltages of two sides. Hence for such a case Series controllers are used. Through series controller we basically vary the series impedance of line in order to control the power flow. In the case of series compensation amount of active power flow directly depends on the percentage of series compensation used.

Some basic features of SSSC

1. It is best way to control the flow of power
2. It is also use for damping of oscillation.
3. It also improves stability of system.

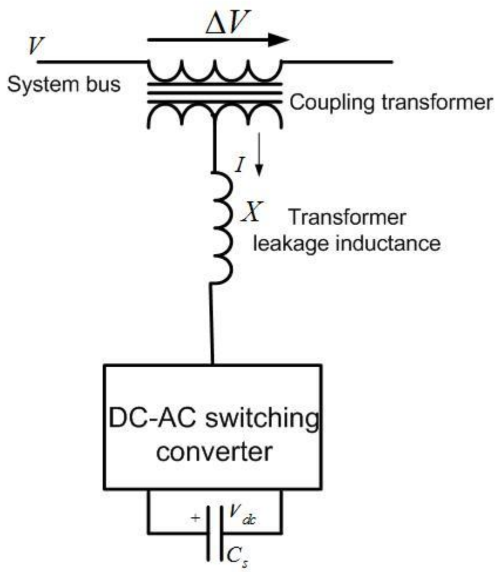

Figure 2.2 schematic diagram of SSSC

2.1.3 UPFC: A Review

Among the all fact devices UPFC is the most useful and powerful facts controller which is applied to improve stability of the power system as well as for better voltage regulation and for better control over power flow. Unified Power Flow Controller, UPFC, basically comprises of two controller, i.e. Series and shunt controller and both the controllers which are connected through a common DC link with a deck storage capacitor, refer Fig. 2.1. Converter 1 i.e. VSC_1 is the shunt controller, which could supply or absorb reactive power as per requirement and at the same time it can fulfill the demand of active power which is done by series controller and flow of active power take place through dc link only. Converter 2 i.e. VSC_2 is the series controller; purpose of which is to supplements an AC voltage in series with line with controllable value of phase angle and magnitude. And important feature of UPFC is that both converters operates freely independent of each other in the view of reactive power, and the active power acquired of series controller i.e. Converter 2, and the losses of converters, are provided by shunt controller through common dc link.

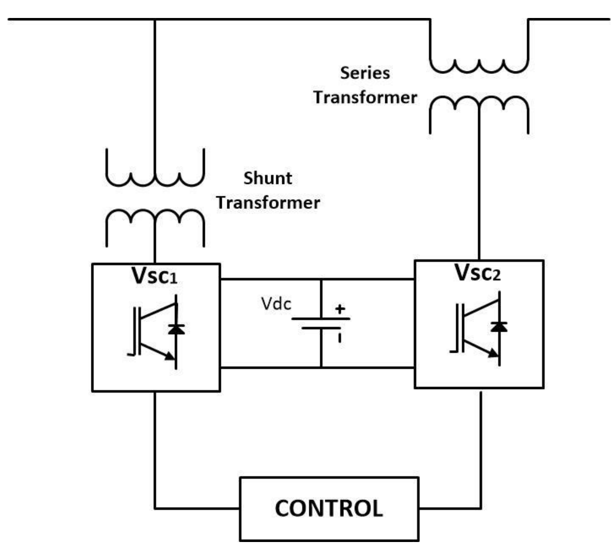

Figure 2.3 Schematic diagram of UPFC

Advantage of UPFC

The UPFC is combination of Series and Shunt controller hence it can serve as STATCOM, SSSC as well as phase angle regulator. Hence UPFC can be used for better voltage regulation and at same time it can control power flow along transmission line. It can be also used to damp out system oscillation and to provide stability to the applied system.

The UPFC can lead to improve the controllability over the flow of power and at the same time the UPFC also improves the system security by improving transient stability limit of system. The UPFC also diminish demand of reactive power by system. And will provide optimal flow of active power flow along the transmission line.

2.2 Distance Relay

2.2.1 Distance Relay Basic

Unlike other protective relay operation of distance relay depends upon the ratio of voltage and current measured by PT and CT respectively. The ratio is none other than the measured impedance of the relay. Now whenever this ratio i.e. measured impedance falls below a certain point, known as reach setting of relay it will operate. In other words relay will trip only when the measured impedance become less than the reach point impedance. As occurrence of the fault leads to rise in the value of current, ratio of voltage to current will be always less than the reach value and causing relay to operate for any fault condition as the impedance of line is proportional to the line length. We can say that relay is going to trip only in the case when fault occurs within a predetermined distance or inside its protection zone.

Hence distance relay will trip whenever

$$Z_{app} < Z_F$$

Where

Z_F : reach setting of distance relay

Z_{app} : apparent impedance seen by relay

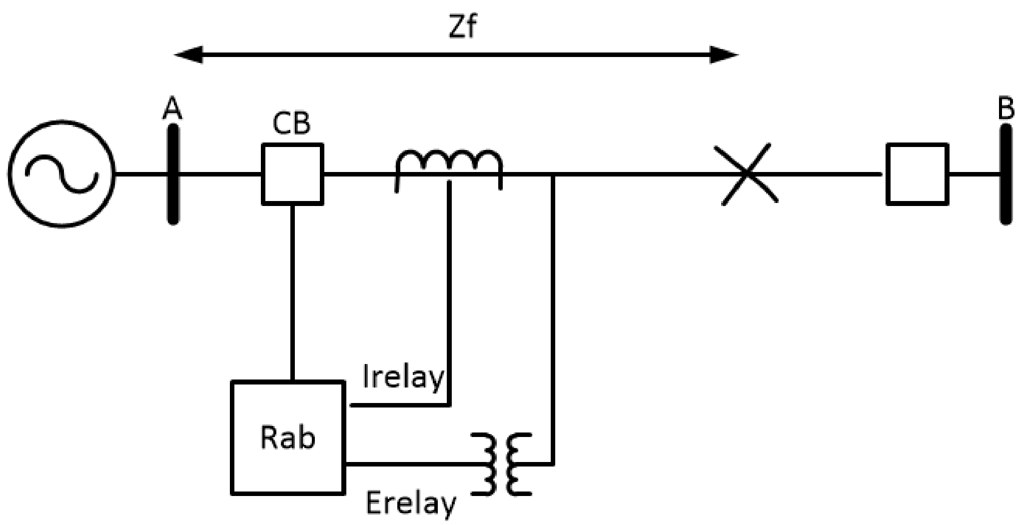

Figure 2.4 The schematic diagram of distance relay

Over reach and under reach of distance relay

- Over reaching of distance relay is case in which relay situated at any terminal operates for fault beyond its operating zone.
- Under reaching of distance relay is case in which relay situated at any terminal does not operate even for fault inside protective zone.

2.2.2 Effect of Power Swing on distance relay

Power swing condition is basically occurs when mechanical input of generator either grater or less than the electrical output of generator that means in the below equation Pa has some positive or negative value. Power swing occurs basically due to power system disturbances such as system fault, sudden load change etc.

$$P_a = P_m - P_e$$

Distance relays must not operate for such a disturbance or power swing, and permit the system to regain its stable operating condition. A Power Swing Block (PSB) function is there in modern relays to avoid such undesired tripping of distance relay during power swing condition. The key function of the PSB function is to discriminate between system faults and power swing condition and block distance to trip in such a condition. However, faults that usually takes place at the time of power swing must be should be identified and cleared with a better selectivity.

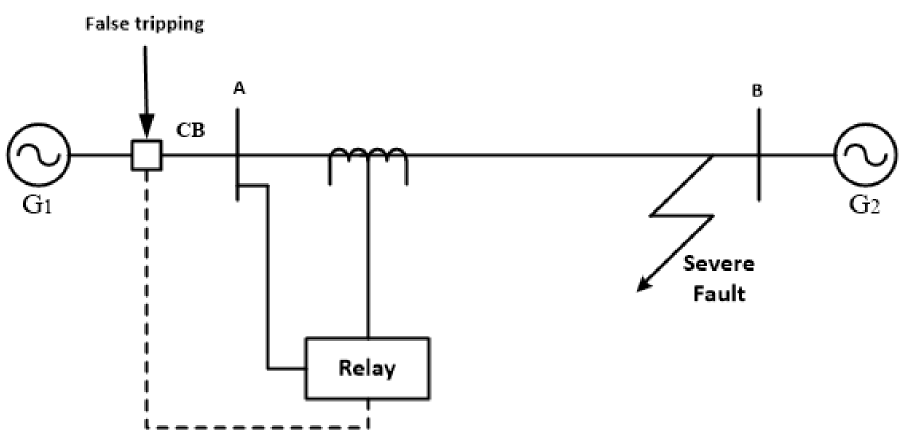

Figure 2.5 False tripping of distance relay due to power swing

2.3 Impact of UPFC on Distance Protection

2.3.1 Apparent Impedance Calculation

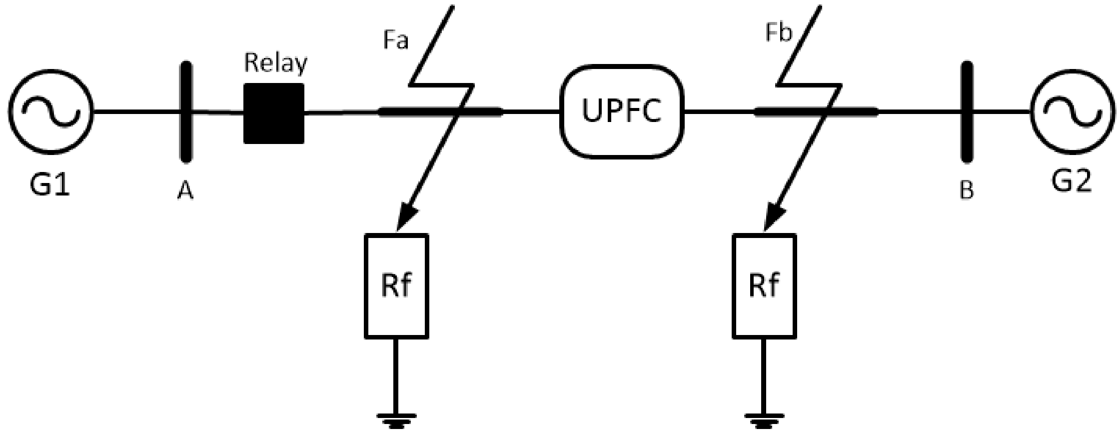

Figure 2.6 Sample network for apparent impedance calculation

Fig.2.6. is schematic diagram of transmission line with UPFC for different location of faults in order to calculate apparent impedance. Measurement of this impedance is basically done by symmetrical component analysis.

2.3.2 Fault before UPFC

Whenever fault occurs in power system before the UPFC i.e. at point b (fault f_b), upfc does not affect the measured impedance as upfc will not be present in fault loop.

2.3.3 L-G fault

Now suppose line to ground fault occurs after the upfc and distance is n*l from the point of relaying. Positive, zero and negative sequence network of the system are given in Fig 2.7,2.8 and 2.9 respectively.

$$V_{1s} = I_{1s}0.5Z_1 + V_{1pq} + I_{1line}\left(n-0.5\right)Z_1 + R_f I_{1f} \tag{2.1}$$

$$V_{2s} = I_{2s}0.5Z_1 + V_{2pq} + I_{2line}\left(n-0.5\right)Z_1 + R_f I_{2f} \tag{2.2}$$

$$V_{0s} = I_{0s}0.5Z_0 + V_{0pq} + I_{0line}\left(n-0.5\right)Z_0 + R_f I_{0f} \tag{2.3}$$

$$I_{1line} = I_{1s} + I_{1sh} \tag{2.4}$$

$$I_{2line} = I_{2s} + I_{2sh} \tag{2.5}$$

$$I_{0line} = I_{0s} + I_{0sh} \tag{2.6}$$

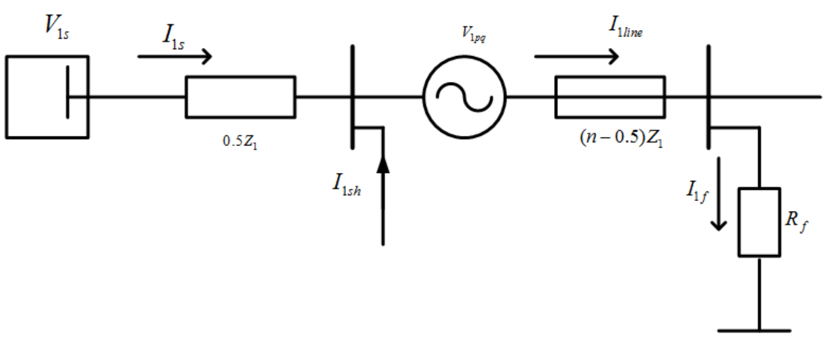

Figure 2.7 positive sequence network

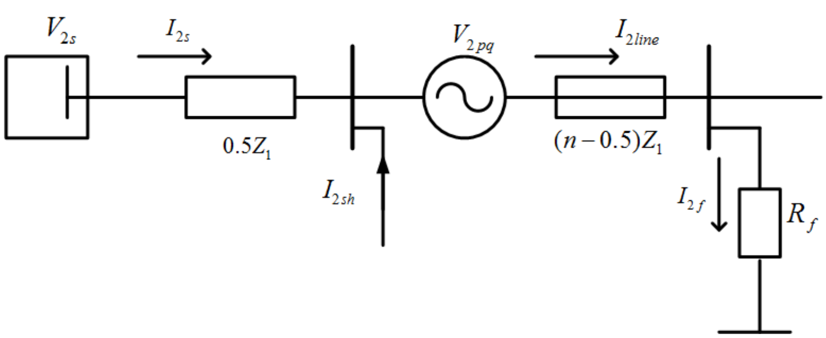

Figure 2.8 negative sequence network

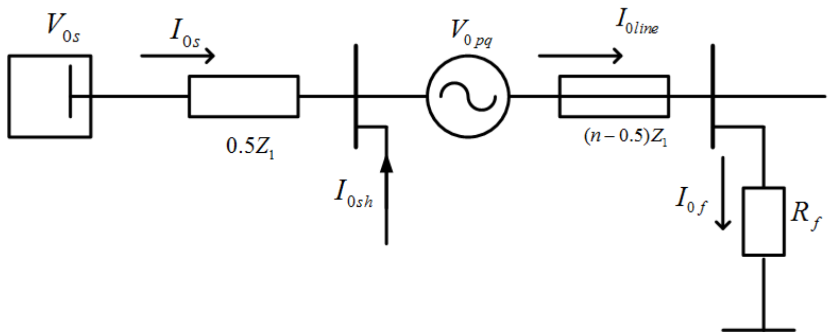

Figure 2.9 zero sequence network

From (2.1) , (2.2) and (2.3) the voltage at the point of relaying can be written as

$$V_s = nI_sZ_1 + nI_{0s}\left(Z_0 - Z_1\right) + I_{sh}\left(n - o.5\right)Z_1 + \left(n - .5\right)I_{0sh}\left(Z_0 - Z_1\right) + V_{pq} + I_fR_f \qquad (2.7)$$

$$V_s = V_{1s} + V_{2s} + V_{0s} \qquad (2.8)$$

$$I_s = I_{1s} + I_{2s} + I_{1s} \qquad (2.9)$$

$$I_{sh} = I_{1sh} + I_{2sh} + I_{0s} \qquad (2.10)$$

$$V_{pq} = V_{1pq} + V_{2pq} + V_{0pq} \qquad (2.11)$$

For the transmission line without UPFC, for L-G fault the impedance seen by distance relay can be obtained from

$$\mathrm{Z} = \frac{\mathrm{V_R}}{\mathrm{I_R} + \dfrac{\mathrm{Z_0} - \mathrm{Z_1}}{\mathrm{Z_1}} \times \mathrm{I_{R0}}} = \frac{\mathrm{V_R}}{\mathrm{I_{Relay}}} \qquad (2.12)$$

Hence, if the distance relay is used in transmission line in the presence of UPFC, the measured impedance will be

$$Z = \frac{V_R}{I_R + \frac{Z_0 - Z_1}{Z_1} \times I_{R0}} = \frac{V_R}{I_{Relay}} \tag{2.13}$$

$$Z = nZ_1 + \frac{I_{sh}}{I_{relay}}\left(n-0.5\right)Z_1 + \frac{I_{0sh}}{I_{relay}}\left(n-0.5\right)\left(Z_0 - Z_1\right) + \frac{V_{pq}}{I_{relay}} + \frac{I_f}{I_{relay}}R_f \tag{2.14}$$

BUT as we know generally one side of the shunt transformer is delta connected, so there will be no zero sequence current injection by STATCOM part of UPFC then the equation (2.14) can be modified as

$$Z = nZ_1 + \frac{I_{sh}}{I_{relay}}\left(n-0.5\right)Z_1 + \frac{V_{pq}}{I_{relay}} + \frac{I_f}{I_{relay}}R_f \tag{2.15}$$

2.3.4 For LL Fault

Now consider the case of LL fault occurs in transmission line after UPFC as per Fig 2.10 .The impedance seen by relay can be written as

$$Z = \frac{V_{a1} - V_{a2}}{I_{a1} - I_{a2}} = \frac{V_b - V_c}{I_b - I_c} \tag{2.16}$$

Hence measured impedance will be

$$Z = nZ_1 + \frac{I_{bsh} - I_{csh}}{I_b - I_c}\left(n-0.5\right)Z_1 + \frac{V_{bpq} - V_{cpq}}{I_b - I_c} + \frac{I_{bf} - I_{cf}}{I_b - I_c}R_f \tag{2.17}$$

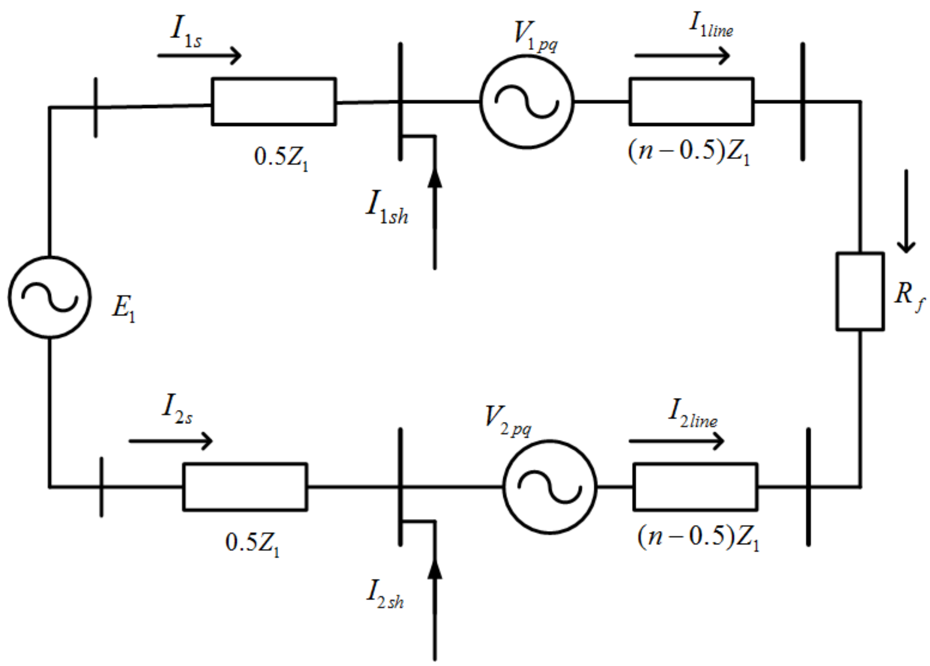

Figure 2.10 sequence network for L-L fault

From the Equation (2.15) and (2.17) it is clear that when the conventional distance relay is used in the transmission system in presence of UPFC during the Line to ground (LG fault) and double line fault (LL fault), the measured impedance has three parts: positive sequence impedance from the relay point to fault point, which is actual impedance to be measured by relay, the 2nd part is because of the UPFC present in fault loop, which can be classified as current injected by the Shunt controller and effect of the variable voltage provided by series controller and the third and last portion of the measured impedance is present because of the fault resistance R_f.

Now if UPFC will be installed at beginning of line with same calculation of apparent impedance Equation (2.15) and (2.17) changes as

$$Z = nZ_1 + \frac{I_{sh}}{I_{relay}}(n)Z_1 + \frac{V_{pq}}{I_{relay}} + \frac{I_f}{I_{relay}}R_f \tag{2.18}$$

$$Z = nZ_1 + \frac{I_{bsh} - I_{csh}}{I_b - I_c}(n)Z_1 + \frac{V_{bpq} - V_{cpq}}{I_b - I_c} + \frac{I_{bf} - I_{cf}}{I_b - I_c} R_f \tag{2.19}$$

From Equation (2.15),(2.17) and (2.18), (2.19) it it can be concluded that impact of UPFC at beginning of line is greater than it is installed at middle of line.

From Equation (2.15) and (2.17) we can say that,

$$Z = nZ_1 + \Delta Z \tag{2.20}$$

Where ΔZ =0 for transmission system without UPFC

If ΔZ is capacitive then apparent impedance will be less than the actual impedance whereas if ΔZ is inductive then apparent impedance will be more than actual value thus relay will either over reach or under reach .

CHAPTER 3

RESULTS AND DISCUSSION

3.1 Simulation of distance relay

3.1.1 Distance Relay model

Transmission line and Distance relay can be modelled using Matlab/Simulink. The Apparent impedance measurement needs the post-fault three phase voltage and current phasors. The three phase current and voltage waveforms taken from the CT and VT respectively are filtered first which is done by the Low Pass Filter (LPF) block. Then, the remaining fundamental voltage and current phasors are passed through Fourier Transform (FFT) block of Simulink. The function of FFT block set is to get the magnitudes and phase angles of fundamental three phase current and voltage phasors. These magnitudes and phase angles then are applied to distance relay algorithm given in Table 3.1 to obtain the apparent impedance. The outputs of distance relay block are the values of resistances and the values of reactance. And simultaneously we can measure impedance with impedance angle. Figure 3.1 shows step by step procedure of how distance relay is built in MATLAB simulink and desired values are obtained.

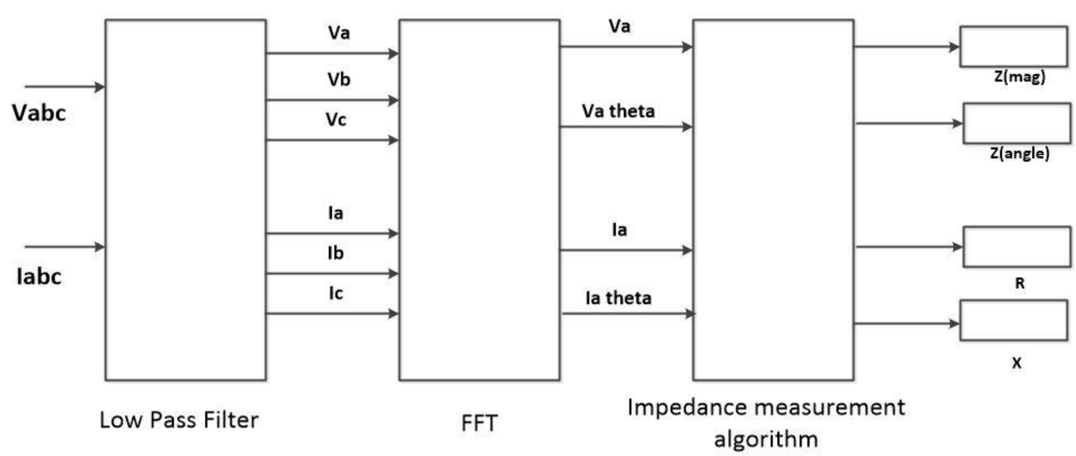

Figure 3.1 Distance relay model

3.1.2 Distance Relay algorithm

There are two types of Faults in power system first is symmetrical and other is unsymmetrical faults. Three phase fault can be defined as fault in which all phases will be contact with each other. Line to ground fault (LG fault), Line to line fault (LL) fault, double line to ground (LLG) comes under symmetrical fault. Whenever a fault occurs in a transmission line , Distance protection basically measures impedance between faulty phase to ground in case of LG fault and in case of LL fault it will be impedance between phases in which fault occurred.Table 3.1 shows the relay algorithm for the analysis.

Table 3.1 Fault impedance calculation for Distance relay

Type of fault	fault	Relay Algorithm
Line to ground fault	X-G	$\frac{V_X}{I_X + 3k_0 I_0}$
	Y-G	$\frac{V_Y}{I_Y + 3k_0 I_0}$
	Z-G	$\frac{V_Z}{I_Z + 3k_0 I_0}$
Line to Line fault	X-Y	$\frac{V_X - V_Y}{I_X - I_Y}$
	YZ	$\frac{V_Y - V_Z}{I_Y - I_Z}$
	ZX	$\frac{V_Z - V_X}{I_Z - I_X}$
Three phase fault	XYZ	$\frac{V_X}{I_X}$

3.2 Simulation of Power System

Simulation of power system with UPFC is done in MATLAB/Simulink using simpower system toolbox. The Simulink model comprises of two 100km transmission line with distributed parameters and UPFC is installed at midpoint of line. STATCOM and SSSC are made by a PWM controlled VSC placing at proper place whereas UPFC is obtained by combination of both with a dc storage capacitor between them and complete analysis has been done for the three phase fault on the line.other system parameters are given in Table 3.2.

Table 3.2 Simulation parameter for power system

Power system element	**parameter**
Line Length L_1,L_2	100km
Voltage	500kv
Nominal frequency	60Hz
Line resistance(R_1, R_2)	0.0254Ω/km
Line resistance (R_0)	0.3864 Ω/km
Line inductance(L_1, L_2)	0.9337e-3 H/km
Line capacitance(C_1, C_2)	4.1264e-3 H/km
Line inductance(L_0)	12.74e-9 F/km
Line capacitance(C_0)	7.751e-9 F/km
Generator Ga	6500 MVA , 500kv
Generator Gb	9000 MVA , 500kv

3.3 Effect of Shunt compensator (STATCOM)

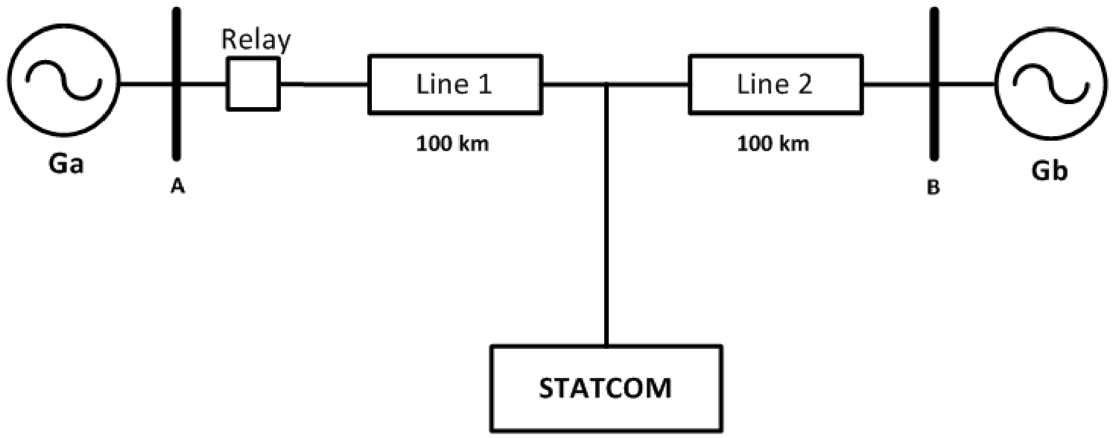

Figure 3.2 STATCOM installed at midpoint of the line

Operation of UPFC can be classified into three ways; first one is when only Shunt Compensator is connected in the transmission line. Such is mode has basic function of improving the voltage profile along the line by proper exchange of reactive power with line.

For only shunt part acting at a time from equation (2.15) for the apparent impedance during L-G fault can be modified as

$$Z = nZ_1 + \frac{I_{sh}}{I_{relay}}(n-0.5)Z_1 \tag{3.1}$$

So it can be seen that when only STATCOM is connected with the transmission line the main contribution in the extra apparent impedance is given by shunt current injected by STATCOM i.e. by I_{sh} .

Now from the simulation R-X characteristics of distance relay with STATCOM at midpoint and in absence of STATCOM can be obtained as shown in Figure 3.3. It can be seen that the two plots are different from each other and Distance relay characteristics with STATCOM has smaller operating region showing under reaching of distance relay. Let us consider fault at location any location with impedance seen by relay will be such that it will be at operating point A, then relay will operate independent of the presence of STATCOM. Similar for point C, it will not trip in both conditions, but if location is such that it comes at point B then relay will not trip even it is inside the protective zone because of the presence of STATCOM, means we can say that the relay will under reach in this case because of the presence of STATCOM, which shows that STATCOM is operating in Capacitive mode delivering reactive power to the system.

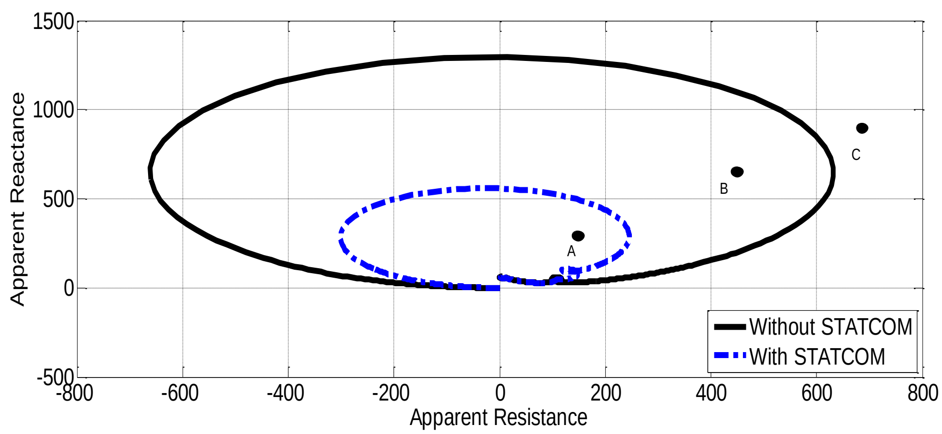

Figure 3.3 R-X plot of Distance Relay

3.3.1 Effect of Fault Location

The apparent and actual impedance obtained from simulation of power system for the STATCOM at midpoint is given in the Table 3.3 which shows that for the three phase fault fault before STATCOM, apparent impedance seen by distance relay is approximately same as actual impedance but for fault after STATCOM it has some higher value than actual impedance.

Table 3.3 Comparison of Actual and apparent impedance

Fault location	Actual impedance	Apparent impedance
20	0.620+j7.678	0.620+j7.674
40	1.236+j15.33	1.236+j15.31
60	1.848+j22.97	1.841+j22.93
80	2.460+j30.61	2.466+j30.53
100	3.074+j38.26	3.060+j38.14
120	3.690+j45.92	3.829+j46.83
140	4.310+j53.61	4.637+j55.61
160	4.936+j61.34	5.496+j64.48
180	5.573+j69.12	6.441+j73.69

Figure 3.4nand figure 3.5 shows the variation of resistance and reactance with the fault location when STATCOM is installed at midpoint of the line.

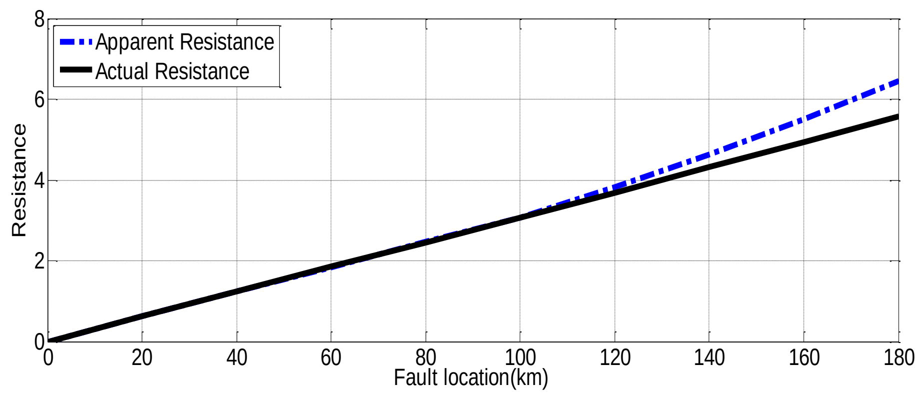

Figure 3.4 Variation of resistance with fault location

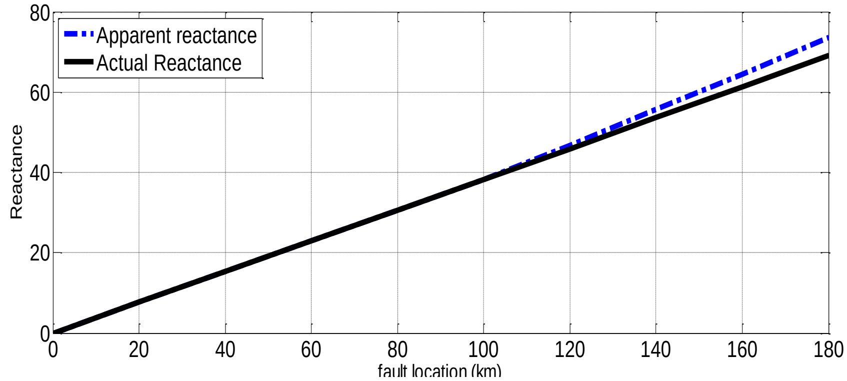

Figure 3.5 Variation of reactance with fault location

Fault location below 100 km shows that the fault occurs before STATCOM's installation point and as we know that when a fault occurs before STATCOM it doesn't affect the performance of relay hence both the curve has the same slope up to that point. But for the fault location resistance and reactance with STATCOM has value higher than that of without STATCOM which is due to STATCOM is inside the fault loop and delievering reactive power to the system and it can be concluded that relay will under reach reach in this case in the presence of STATCOM.

3.3.2 Effect of STATCOM location

Installation point of STATCOM is also an important point for analysis of performance of relay and it has significant effect on the measured impedance of the distance relay. To analyze its effect we placed STATCOM at beginning say at 10 km away from the generator G_A and there is a three phase fault at location of 160 km then the measured impedance is 7.576+j72.89 Ω which is greater as compared to the value for STATCOM at the midpoint which was 5.496+j64.48Ω while actual impedance to be measured by relay is 4.936+j61.34 Ω .Hence we can say that STATCOM has greater impact on performance of relay when it is connected at the beginning of line.

3.3.3 Effect of Degree of Compensation

All above calculation are made for the STATCOM operating in capacitive mode, now if we control the modulation of the PWM generator such that STATCOM starts to take reactive power from the system then its effect on the distance relay will be completely different. For such a condition it basically lowers the value of apparent impedance seen by relay as location and may cause relay to over reach.Figure 3.6 and 3.7 shows the variation of resistance and reactance of relay with different fault location, it shows that with fault location apparent impedance decreases which may cause relay to over reach, it also shows that its effect dominates for the greater values of fault location, this is because influence ration I_{sh}/I_{relay} increases with the location of fault.

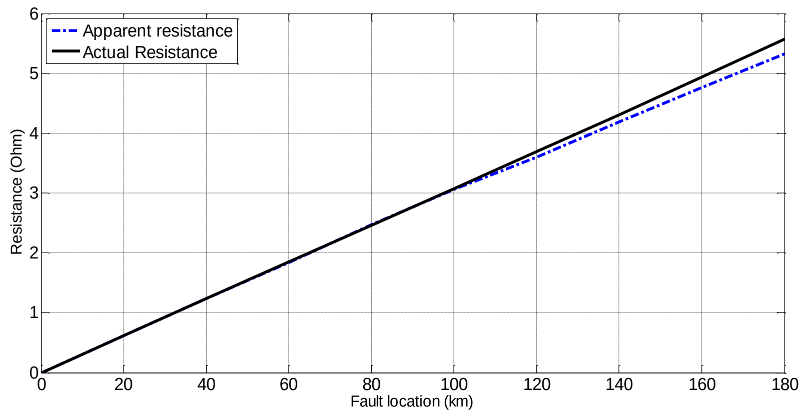

Figure 3.6 Variation of resistance with fault location

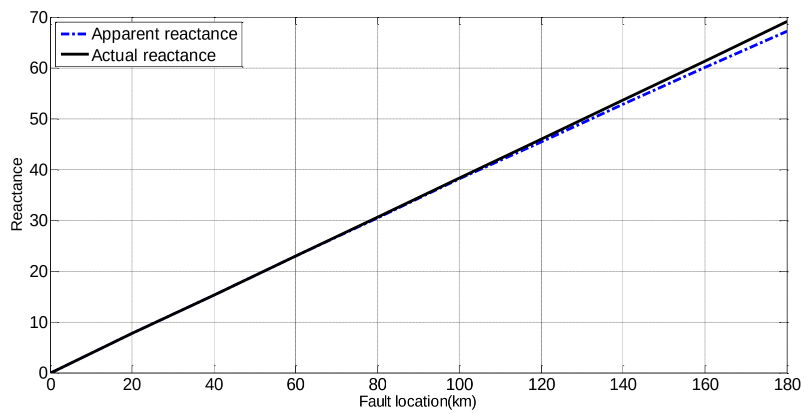

Figure 3.7 Variation of reactance with fault location

3.4 Effect of Series compensator (SSSC)

Now consider the case when only SSSC is connected in the midpoint of transmission line.SSSC is like a variable series capacitor or reactor which control power flow along the line. Hence its operation cause performance degradation of distance relay. Figure 3.8 shows the power system with SSSC at the midpoint of line.

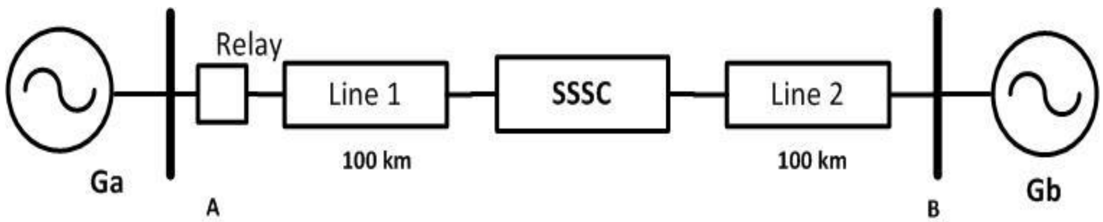

Figure 3.8 SSSC installed at midpoint of line

Now from the simulation R-X characteristics of distance relay with SSSC at midpoint with and without SSSC can be obtained as shown in Figure 3.9.It can be seen from the plot that the characteristics with SSSC has lesser operating region compared to the curve without SSSC.Which means distance relay may not operate for the fault inside the protection zone because of the presence of SSSC in the line.

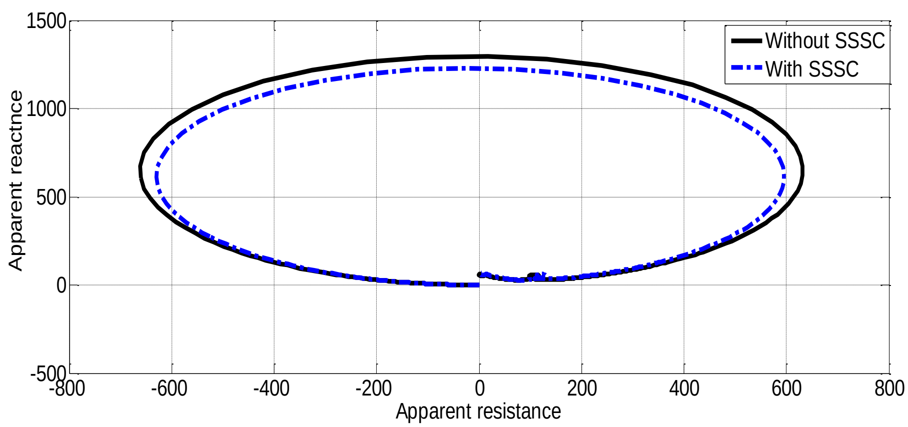

Figure 3.9 R-X plot of Distance Relay

Effect of Fault Location

The apparent and actual impedance obtained from simulation of power system for the SSSC at midpoint is given in the Table 3.4 which shows that for the fault before SSSC, apparent impedance seen by distance relay is approximately same as actual impedance but for fault after SSSC it has some higher value than actual impedance as it is operating in inductive compensation mode.

As the fault location is increasing the series compensator influence ratio V_{pq}/I_{relay} is increasing which is causing apparent impedance of relay to rise.

Table 3.4 Comparison of apparent and actual impedance

Fault location	Actual impedance	Apparent impedance
20	0.620+j7.678	0.621+j7.629
40	1.236+j15.33	1.236+j15.33
60	1.848+j22.97	1.849+j22.98
80	2.460+j30.61	2.462+j30.62
100	3.074+j38.26	3.076+j38.27
120	3.690+j45.92	4.025+j51.82
140	4.310+j53.61	4.668+j59.76
160	4.936+j61.34	5.320+j67.75
180	5.573+j69.12	5.982+j75.78

3.5 Effect of UPFC on relay

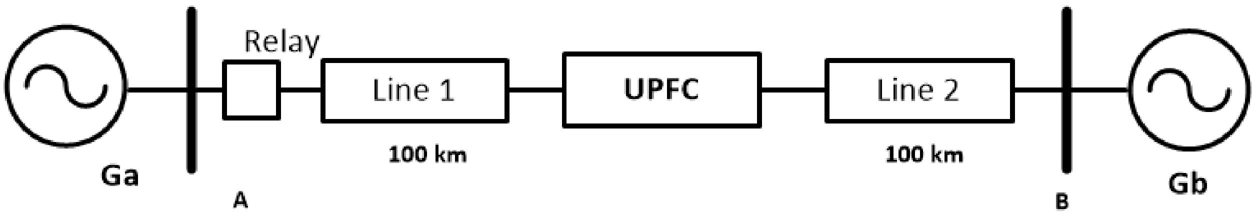

Figure 3.10 UPFC installed at midpoint of line

Now if we connect series compensator i.e. SSSC in series with the line such that it is connected with STATCOM via dc link with a capacitor i.e. UPFC is now in operation with the transmission line. R-X characteristics of distance relay without compensation and with facts devices is shown in fig. 3.11 . We have considered UPFC and STATCOM under the FACTS device. It can be seen that the these curves are completely different from each other.

- Compared to STATCOM ,UPFC has greater influence on the apparent resistance seen by relay because of active power consumption of both Series and Shunt devices.
- UPFC has greater impact on apparent reactance of relay because of reactive power exchange by both SSSC and STATCOM.

Hence Presence of UPFC cause trip boundary of relay to change which can be lead to mal operation of the distance relay.iIn this case UPFC is causing under reaching of distance relay.

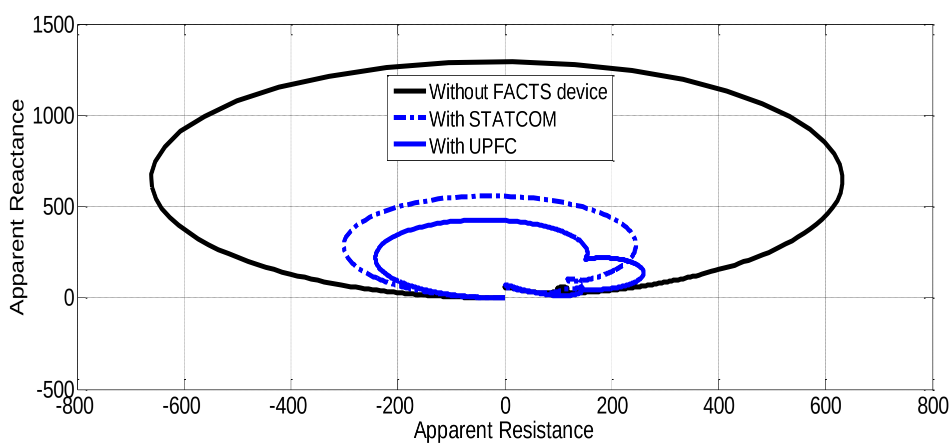

Figure 3.11 R-X plot of Distance Relay

3.5.1 Effect of Fault Location

The apparent and actual impedance obtained from simulation of power system for the UPFC at midpoint is given in the Table 3.5 which shows that for the fault before UPFC, apparent impedance seen by distance relay is approximately same as actual impedance but for fault after UPFC it has some higher value than actual impedance as both STATCOM and SSSC are contributing in the same manner.

Table 3.5 comparison of apparent and actual impedance

Fault location	Actual impedance	Apparent impedance
20	0.620+j7.678	0.620+j7.674
40	1.236+j15.33	1.232+j15.32
60	1.848+j22.97	1.841+j23.00
80	2.460+j30.61	2.448+j30.67
100	3.074+j38.26	3.053+j38.33
120	3.690+j45.92	4.596+j53.26
140	4.310+j53.61	5.601+j62.50
160	4.936+j61.34	6.650+j71.77
180	5.573+j69.12	7.841+j81.43

Figure 3.12 and Figure 3.13 shows the variation of impedance with the fault location when UPFC is installed at midpoint of the line and can be compared with effect of STATCOM on relay on the same plot. Fault location below 100 km shows that the fault occurs before UPFC installation point and as we know that when a fault occurs before UPFC it doesn’t affect the performance of relay hence both the curve has the same slope up to that point. But after 100 km resistance and reactance

increases for the system with UPFC with increase in fault location .And as mentioned before effect of UPFC is greater than that of STATCOM for the fault after 100km of the line.

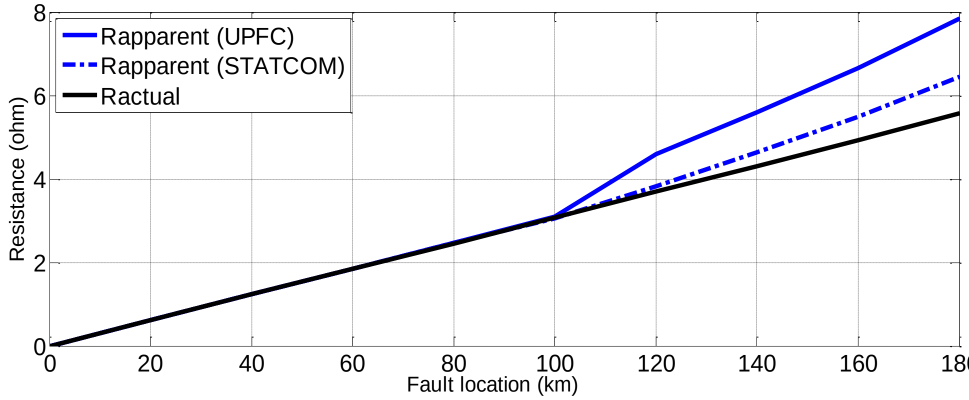

Figure 3.12 Variation of resistance with fault location

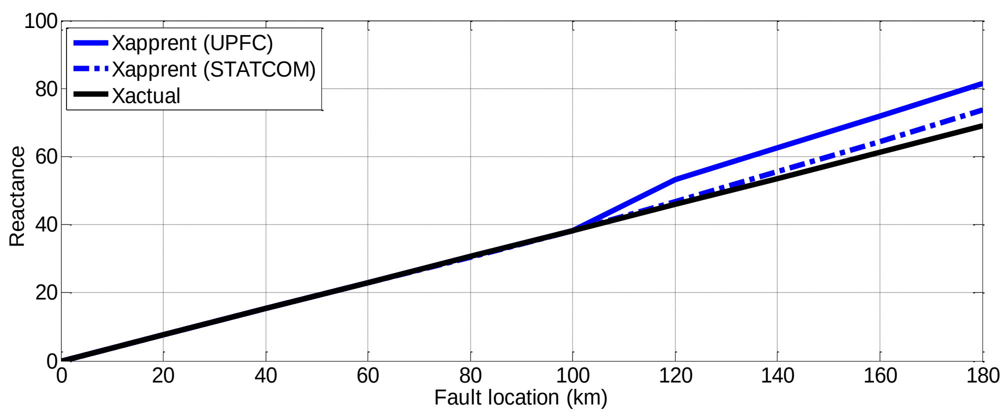

Figure 3.13 Variation of reactance with fault location

3.5.2 Effect of UPFC location

Installation point of UPFC is also an important point for analysis of performance of relay and it has significant effect on the measured impedance of the distance relay.From eq (2.18) and (2.19) we have concluded that UPFC has greater impact on distance relay operation it it is installed at beginning of the line ,which can be proved simulation also,for that we kept UPFC at starting of line say at 10 km and there is a three phase fault at location of 160 km then the measured impedance is 9.329+j78.65 Ω which is greater as compared to the value for STATCOM at the midpoint which was 5.645+j67.09 Ω.

Fig. 3.14 shows R-X plot of the distance relay for the system with at without FACTS devices to analyse its effect and FACTS device is considered for two differet location first at midpoint of line and other one at starting of line (at 100km of line). We can observe that UPFC has greater influence when it is installed at starting of the line.

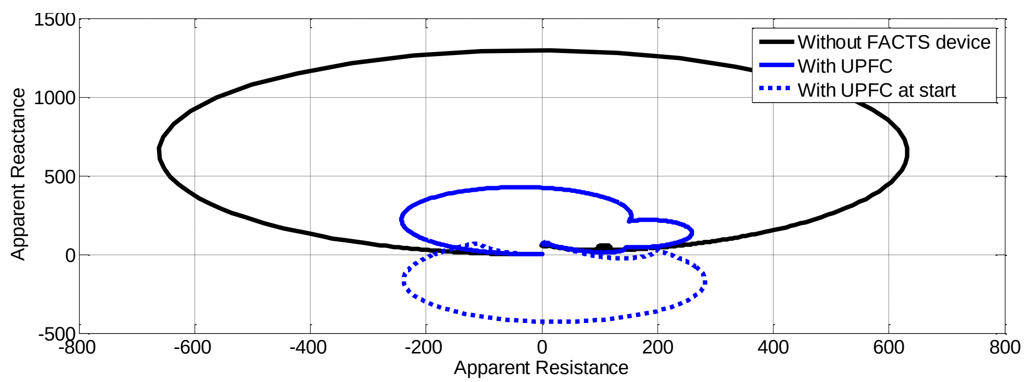

Figure 3.14 R-X plot of Distance Relay

CHAPTER 4

CONCLUSION AND FUTURE SCOPE

4.1 Conclusion

In the study performance of distance relay is analyzed for the ransmission line with various fault and its location in presence of STATCOM and UPFC .When fault occurs in the system before the installation point of the FACTS compensator whether it is STATCOM or UPFC it doesn’t have any impact on the performance of distance relay as value of measured impedance is same for both case.

Now if fault occurs beyond the installation point of the FACTS device relay may over reach or under reach depending upon the fault location and degree of compensation. When we observed system with STATCOM it is clear that when it operates as a inductor taking reactive power from the system it may cause relay to over reach and vice versa.Similarily for the SSSC in operation, if it acts as series capacitor means it reduces the impedance of the line leads to lower value of apparent impedance and in turn can cause over reach of the relay and vice versa. Now coming to combine operation of STATCOM and SSSC i.e. UPFC is connected in the line it depends upon the location of fault and compensation of the both devices.

4.2 Future Scope

The proposed work can be extended for the analysis of the relay performance in presence of UPFC with various fault condition which are not included in the this study .Analysis can also be done for the different FACTS devices other than UPFC with wide variation in system parameter.Based on the analysis of impact approach for new setting principle of distance relay can be studied.

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